Published in Biochimica et Biophysica Acta
Vol. 252, pp. 285-295, Nov. 1971

AFRRI SR70-3
APRIL 1970

AFRRI
SCIENTIFIC
REPORT



# ACTIVITY OF RAT LIVER ENZYMES RESPONSIBLE FOR GLYCOGEN METABOLISM AFTER WHOLE-BODY IRRADIATION

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
Defense Atomic Support Agency
Bethesda, Maryland

This report has been approved for open publication by the Department of Defense

All aspects of investigative programs involving the use of laboratory animals sponsored by DOD components are conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care", prepared by the National Academy of Sciences - National Research Council.

AFRRI SR70-3
April 1970

# ACTIVITY OF RAT LIVER ENZYMES RESPONSIBLE FOR GLYCOGEN METABOLISM AFTER WHOLE-BODY IRRADIATION

G. N. CATRAVAS
C. G. McHALE

S. J. BAUM
Chairman
Experimental Pathology Department

HUGH B. MITCHELL
Colonel, USAF, MC
Director

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
Defense Atomic Support Agency
Bethesda, Maryland

---

## ACKNOWLEDGMENT

The authors wish to thank O. Z. Williams for his able and valuable assistance during the course of this study. They also wish to express their appreciation to the members of the reactor, radiological physics and radiological safety groups.

TABLE OF CONTENTS

LIST OF FIGURES

## FOREWORD
(Nontechnical summary)

Glycogen is a term which applies to a group of complex sugars present in most animal cells as well as certain plants. In mammalian systems glycogen is found primarily in liver and muscle and constitutes an important store of energy. Liver glycogen is broken down to glucose which then passes into the blood stream for use by the tissues. Muscle glycogen is utilized as a source of energy for muscle contraction.

Glycogen is a highly branched macromolecule and is essentially composed of $\alpha$-glucose units joined by 1, 4 and 1, 6 glucosidic bonds. Two enzymes (amylophosphorylase and amylo-1, 6-glucosidase) are mainly responsible for the in vivo breakdown of liver glycogen to glucose, and two enzymes (UDPG-glycogen transglucosylase and amylo-(1, 4→ 1, 6)-transglucosidase) catalyze its synthesis.

It has been reported that the glycogen content of the liver of rats and other animals increases considerably after irradiation. It was therefore of interest to determine the effects of radiation on the individual liver enzyme activities which are responsible for its in vivo breakdown and synthesis. Two different radiation sources (x-ray generator and mixed gamma-neutron radiation from the AFRRI-TRIGA reactor) were used in this study. Under our experimental conditions, the activities of the enzymes studied are greatly affected. The results obtained show that the activity of the enzymes responsible for the breakdown of glycogen is greatly inhibited. A significant inhibition was observed also in the activity of 1, 4→ 1, 6 transglucosidase which catalyzes the formation of 1, 6 glucosidic bonds. However, it was found that the

activity of UDPG-glycogen transglucosylase, which is responsible for the *in vivo* synthesis of polysaccharides containing 1,4 glucosidic bonds, is greatly enhanced.

## ABSTRACT

The activities of liver enzymes involved in the breakdown and synthesis of glycogen have been investigated in rats exposed to 1200 rads midline kerma dose, free-in-air, of x rays or mixed gamma-neutron radiation.

It was found that glycogen phosphorylase and amylo-1,6-glucosidase, both of which are involved in the breakdown of glycogen to "glucose" units, are greatly inhibited by both qualities of radiation. A considerable inhibition in the activity of amylo-(1,4 →1,6)-transglucosidase (branching enzyme) was also observed. In contrast, it was found that the activity of UDP-glucose-glycogen transglucosylase which is responsible for the in vivo synthesis of 1,4-polysaccharides is greatly enhanced when the animal received x rays or mixed gamma-neutron radiation.

# I. INTRODUCTION

It has been reported that x irradiation results in changes in the level of liver glycogen and that in rats and mice, which were starved for 24 hours before and/or after irradiation, the glycogen content of the liver was higher than in control animals of the same nutritional condition.[2, 10, 11, 15, 19, 20] Concurrent with the rise of the liver glycogen, increased blood glucose levels have been observed.[11, 15, 20] The activities of the enzymes phosphofructokinase and fructose-1, 6-diphosphatase, which play regulatory roles in glycolysis, were measured in the liver of mice exposed to 690 R of whole-body x rays and, on the basis of the results obtained, it was concluded that glycolysis is not diminished after x irradiation.[3]

In order to obtain information on the cause of the glycogen accumulation observed by investigators cited above, the objective of this study is to determine the in vivo changes induced by ionizing radiations in the activities of the liver enzymes glycogen phosphorylase, amylo-1, 6-glucosidase, UDPG-glycogen transglucosylase and glycogen 1, 4 → 1, 6 transglucosidase which are involved in the breakdown and synthesis of glycogen as shown in Figure 1.

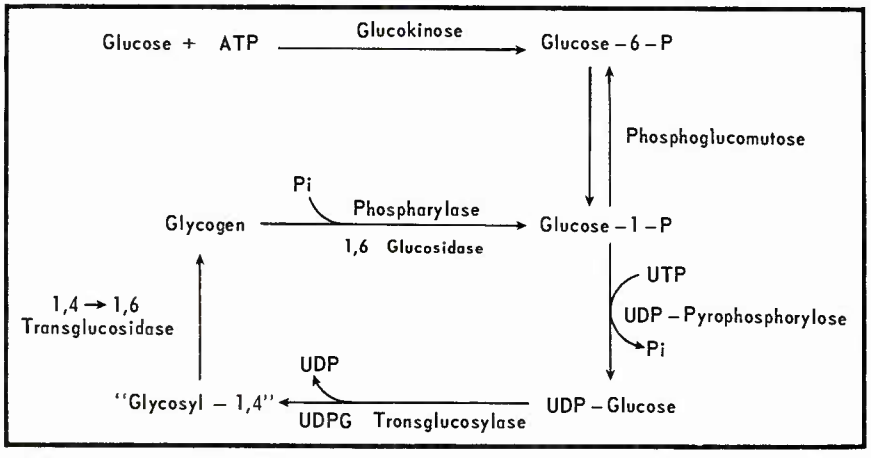


Figure 1. Reactions involved in the breakdown and synthesis of glycogen

## II. PROCEDURES

Female Sprague-Dawley rats weighing 90 to 110 grams were used in this study. All animals were kept on a fat-free diet at least 7 days prior to irradiation, and had free access to water. Each animal was fed with approximately 12-13 grams of food (dry weight) per day. The entire ration was given at one time and the rats were trained to consume it within 1 to 1-1/2 hours. The animals were exposed to radiation approximately 2 hours after they had consumed their food.

This study employed 216 rats, utilizing 27 animals in each of 8 experiments. These 27 animals were divided into three groups as follows: nine rats were sham irradiated and used as controls, nine rats were irradiated with x rays and nine rats were exposed to mixed gamma-neutron radiation. During exposure the animals were individually housed in Lucite boxes which were so arranged that each rat received an equal unilateral exposure. The tissue kerma rate, free-in-air, at the midline of the animal was 20 rads/min; the total dose was 1200 rads. The physical characteristics of the exposure sources were as follows:

X rays. A 250 kVp x-ray generator with inherent filtration of 1.2 mm beryllium and added filtration of 0.95 mm copper was used. The distance from the source to the midline of each rat was 100 cm.

Mixed gamma-neutron radiation. The AFRRI-TRIGA reactor was used as the radiation source. The rats, individually housed in Lucite boxes, were placed in the exposure room so that the kerma to each rat did not vary by more than 4-5 percent. The distance of the animals from the center line of the reactor was 292 cm. The ratio of gamma to neutron tissue kermas, free-in-air, was approximately 1.5. This was

measured using a paired chamber technique, i.e., a 50 $cm^3$ tissue-equivalent chamber filled with tissue-equivalent gas, and a 50 $cm^3$ graphite chamber filled with $CO_2$. On all Lucite boxes sulfur tablets were used for neutron monitoring. The total doses were determined by measurements made with a 50 $cm^3$ tissue-equivalent chamber filled with tissue-equivalent gas.

Approximately 75 percent of the neutrons had energies between 10 keV and 3 MeV. The remaining 25 percent had an energy in excess of 3 MeV. The average energy of the gamma component is believed to be of the order of 1 to 2 MeV.

Preparation of enzyme systems. Following removal from the exposure room, three animals from each experimental group as well as from the sham irradiated controls were sacrificed by decapitation at 24, 48, or 72 hours postirradiation. The livers were immediately excised, chilled and homogenized in 2.5 volumes of ice-cold water. When glycogen phosphorylase was to be determined, 50 mmoles of NaF per ml were added to the water. The homogenates were centrifuged for 30 minutes at 40,000 x g and the clear supernatants were used for enzymic activity determinations.

Phosphorylase. Phosphorylase activity was measured in the direction of synthesis of polysaccharide, since this enzyme is capable in vitro of constructing a polysaccharide composed of $\alpha$-1,4 glycosyl units.[24] The activity was determined by measuring the rate of liberation of inorganic phosphate from glucose-1-phosphate in the presence of glycogen.[5] Inorganic phosphate was determined by the method of Fiske and SubbaRow.[9] The intensity of the color which was developed was measured in a Bausch and Lomb colorimeter at 660 nm.

The assay mixture (1.2 ml), slightly modified from Sutherland's procedure,[22] contained 2 μmoles adenosine-5'-monophosphate; 1.5 μmoles $MgCl_2$; 50 μmoles glucose-1-phosphate (K salt, pH 6.2); 5.7 mg glycogen; and 50 μmoles NaF. The assay mixture was kept in an ice bath. The addition of 0.3 ml of enzyme preparation to the mixture initiated the reaction. A sample (0.5 ml) was withdrawn at the time the enzyme was added (zero time) and placed in 0.5 ml of 4 percent trichloroacetic acid (TCA). The remaining mixture was incubated for 20 minutes at 37°C. The reaction was stopped by the addition of 1.0 ml of 4 percent TCA. After centrifugation for 10 minutes at approximately 1000 x g, the supernatants were decanted and used for phosphorus determination.

1,6 Glucosidase. The assay mixture (0.55 ml) contained 50 μmoles potassium phosphate pH 6.8, and 1 mg glycogen, glucose-free. To this solution, kept in an ice bath, was added 0.01 ml of α-phosphorylase suspension in 0.0015 M EDTA, 0.1 M NaF, 0.00192 M Na glycerophosphate (pH 6.8; 15.5 mg protein/ml; Sigma Co.), and 0.1 ml enzyme preparation (approximately 2 mg protein). The mixture was incubated for 20 minutes at 30°C and the reaction was stopped by the addition of 0.8 ml of 4 percent TCA. The precipitate was removed by centrifugation, and the supernatant was heated in a boiling water bath for 10 minutes to hydrolyze any glucose-1-phosphate or glucose-6-phosphate present. It was then neutralized with 0.3 N NaOH, and the liberated glucose was determined colorimetrically by the Somogyi-Nelson method.[18]

UDPG Transglucosyláse. The assay mixture (0.30 ml) contained 6.0 μmoles Tris-HCl pH 7.4; 60 μmoles UDP-glucose; 2.4 μmoles EDTA and 1.0 mg glycogen.

To this solution, kept in an ice bath, was added 0.5 ml of enzyme preparation (approximately 10 mg protein). A sample (0.4 ml) was taken from this mixture at zero time and mixed with 40 percent NaOH (0.4 ml). The balance was incubated at 37°C for 45 minutes and the reaction was stopped by the addition of 0.4 ml of 40 percent NaOH. The "zero time" sample and the incubated mixture were digested by heating for 15 minutes at 100°C. They were then cooled in an ice bath and cold absolute ethanol (3 to 4 volumes) was added to precipitate the glycogen. After centrifuging for 10 minutes at approximately 1000 x g, the clear supernatants were decanted and the precipitates were dissolved in 0.02 M Tris-HCl buffer pH 7.4 (0.5 ml). Eighty percent phenol (0.4 ml) and concentrated $H_2SO_4$ (1.8 ml) were then added and the color which was developed, in approximately 30 minutes, was measured colorimetrically at 490 nm.[16]

1,4→1,6 Transglucosidase. The Larner method[12] with slight modifications was used for the determination of transglucosidase activity. The assay mixture (0.8 ml) contained 100 μmoles Tris-HCl (pH 7.9), and 1.5 mg corn amylopectin. To this solution was added 0.8 ml of enzyme preparation (approximately 15 mg protein). A sample (0.8 ml) was taken at zero time and deproteinized with 0.8 ml of 3 percent perchloric acid. The balance was incubated for 15 minutes at 30°C. The reaction was stopped by the addition of 0.8 ml of 3 percent perchloric acid, and after removing the precipitates by centrifugation the supernatants were neutralized to pH 7 with solid $NaHCO_3$. The color which was developed on addition of a solution of iodine (0.2 percent I + 0.4 percent KI) was measured colorimetrically at 570 nm.

## III. RESULTS

The effect of ionizing radiation on the activity of glycogen phosphorylase, which is responsible for the in vivo hydrolysis of 1, 4 glucosidic bonds is shown in Figure 2. For comparison purposes, phosphorylase activity in the liver of unirradiated control animals was set at 100 percent. It can be seen in this figure that the activity of this enzyme is greatly inhibited by radiation from either source. It is also indicated in

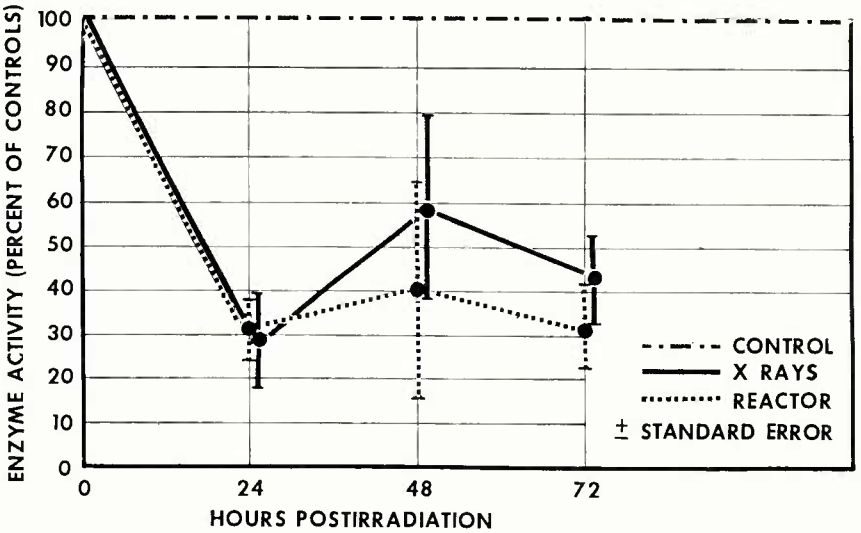


Figure 2. Effect of 1200 rads x rays or mixed gamma-neutron radiation on the activity of glycogen phosphorylase

this figure that the inhibition is more pronounced 1 day after irradiation and it appears that a slight, temporary, recovery occurs 24 hours later. Figure 3 shows the effect of radiation on the activity of amylo-1, 6-glucosidase which catalyzes the in vivo hydrolysis of 1, 6 glucosidic bonds. It can be seen that both qualities of radiation inhibit the activity of this enzyme.

The changes induced in the activity of UDPG-transglucosylase which is responsible for the in vivo synthesis of polysaccharides containing 1, 4 glucosidic bonds are presented in Figure 4. It can be seen in this figure that the activity of this enzyme

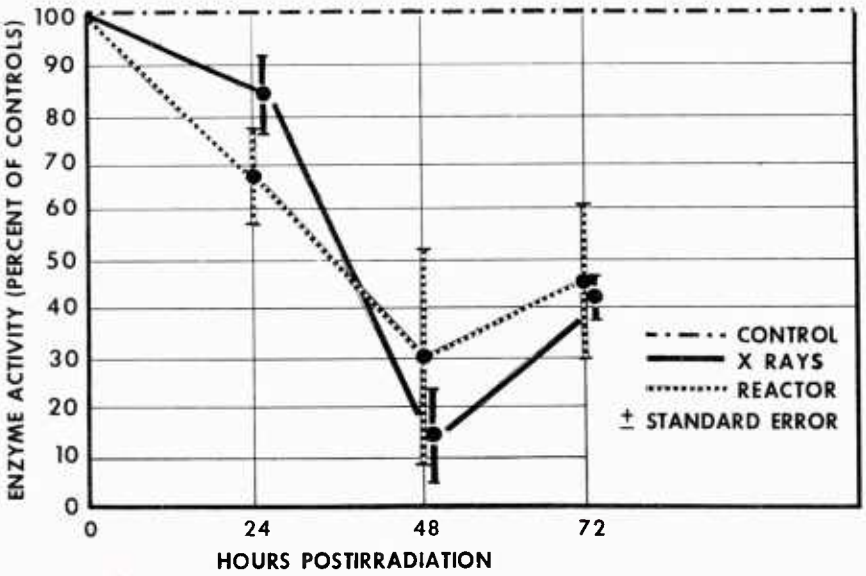


Figure 3. Effect of 1200 rads x rays or mixed gamma-neutron radiation on the activity of amylo-1, 6-glucosidase

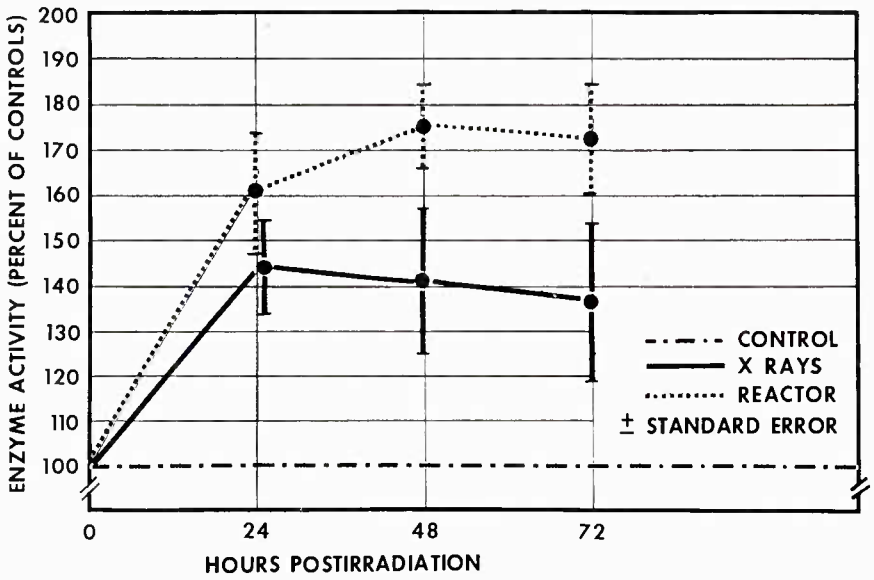


Figure 4. Effect of 1200 rads x rays or mixed gamma-neutron radiation on the activity of UDPG-glycogen transglucosylase

is greatly enhanced by ionizing radiation when the rats were subjected to 1200 rads of x rays or mixed gamma-neutron radiation.

Figure 5 shows the activity changes induced by radiation to the enzyme 1,4→1,6 transglucosidase which catalyzes the in vivo formation of 1,6 glucosidic bonds. The results indicate that the activity of this enzyme is inhibited by both qualities of radiation 24 hours postirradiation and it appears that recovery occurs in x irradiated rats 48 and 72 hours after exposure. The gamma-neutron exposed rats indicate possible recovery 48 hours postirradiation but a further decrease is observe 72 hours after exposure.

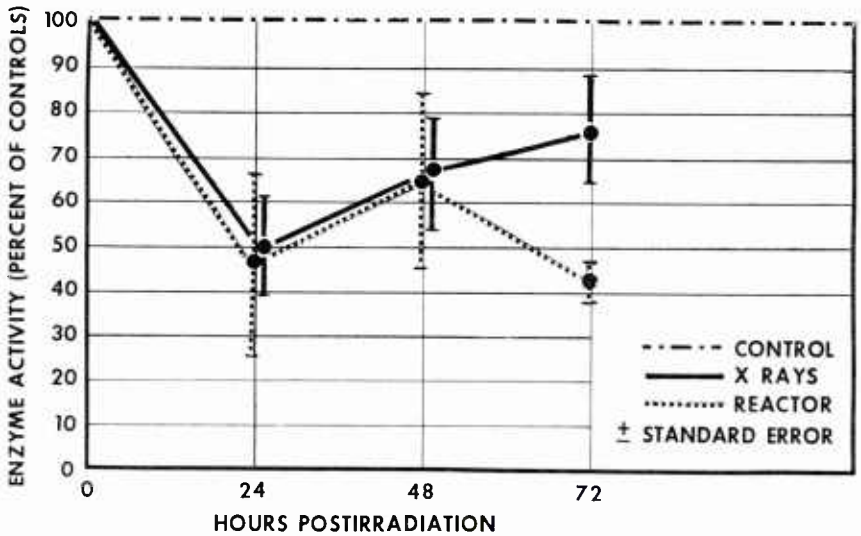


Figure 5. Effect of 1200 rads x rays or mixed gamma-neutron radiation on the activity of glycogen 1,4→1,6 transglucosidase

## IV. DISCUSSION

It is well-known that starvation results in decrease of the deposits of tissue glycogen in the animal and that in rats starved for 24 to 30 hours the liver is practically depleted of glycogen.[25] However, it has been shown that after whole-body x irradiation of rats and mice which were deprived of food before and/or after exposure, the liver glycogen was highly increased.[2,10,11,15] It is reasonable to assume that the observed elevated values of glycogen may be due either to an increased synthesis

or a decreased rate of glycogen breakdown. To clarify the observation of elevated glycogen, the effect of x rays on the activity of enzymes playing key roles in glucose breakdown and glucogenesis has been investigated over periods of several days after whole-body x irradiation. It was found[3,4] that in mice exposed to 690 R of x rays and starved 24 hours prior to the experimental sacrifice, phosphofructokinase activity is considerably enhanced whereas fructose-1,6-diphosphatase is stimulated to a much lesser degree. Pyruvate kinase and phosphoenolpyruvate carboxykinase, which link glucose breakdown to the TCA cycle and therefore play a regulatory role in gluconeogenesis, are also affected by x irradiation.

Increase in the levels of fructose-1,6-diphosphate and dihydroxyacetone phosphate has been observed in the liver of mice exposed to 690 R of x rays and starved for 24 hours before killing. Pyruvate, lactate and phosphoenolpyruvate levels were almost unchanged. However, none of these glycolysis intermediates were significantly increased or diminished at the time of highest liver glycogen content.[2] Elevated values of $\alpha$-glycerophosphate were found in the livers of irradiated mice,[1] and it was concluded that an enhancement of lipid degradation after irradiation may represent an additional source of glycogen precursors.

On the other hand, evidence has been presented[17] which indicates that in x irradiated (600 R) fasted rats there is no increase in the net synthesis of glucose and such evidence excludes involvement of glucocorticoids to account for increased deposition of liver glycogen and elevated blood glucose levels. Enhancement in the activities of liver enzymes involved in amino acid deamination has been observed in rats exposed to 600 R of x rays, whereas fructose-1,6-diphosphatase and

glucose-6-phosphatase did not seem to be affected. Glucose ATP phosphotransferase and glycogen phosphorylase showed immediate reduction and enhancement, respectively, in their activities, though normal levels were restored within a day after irradiation and maintained throughout the period of investigation.[6]

The effect of x rays and mixed gamma-neutron radiation on the liver enzymes which are involved in the breakdown and synthesis of glycogen from glucose (Figure 1) has been investigated in this study and it was found that, under our experimental conditions, the activities of the enzymes studied are greatly affected by radiation. Although the rats were not studied immediately after irradiation in these experiments, it has been found that, in contrast to the results obtained with 600 R of x rays by other investigators,[6] in rats subjected to 1200 rads of x rays or mixed gamma-neutron radiation and sacrificed at 24, 48 or 72 hours after exposure, glycogen phosphorylase and amylo-1,6-glucosidase activities are greatly decreased by both qualities of radiation (Figures 2 and 3). Both these enzymes are involved in the breakdown of glycogen to "glucose" units.

While the in vitro synthesis of glycogen is readily accomplished by the combined action of phosphorylase and the branching enzyme, the equilibrium condition in vivo does not favor the synthesis of glycogen by this pathway.[21] Instead, it has been shown that glycogen is synthesized, in both liver and muscle, from UDP-glucose-glycogen transglucosylase,[13] in combination with the branching enzyme. It was found in this study that, in contrast to the inhibiting effect of radiation on phosphorylase and amylo-1,6-glucosidase, the activity of UDPG-glycogen transglucosylase (UDPG-glycogen transferase) is greatly enhanced when the animal received x rays or mixed gamma-neutron radiation (Figure 4), whereas the activity of

1,4→1,6 transglucosidase (branching enzyme) is impaired by radiation (Figure 5). Since these two glycogen synthesizing enzymes act concurrently, not only the specificities of the enzymes themselves but also their relative activities would strongly influence the average chain lengths and therefore the degree of branching of the glycogen molecule synthesized. The fact, therefore, that the activity of the one enzyme is enhanced by radiation whereas that of the second is impaired, could result in the synthesis of a glycogen molecule with a different degree of branching. However, this possibility has not been investigated in this study.

The results obtained indicate that in the irradiated rat, under our experimental conditions, glycogen hydrolysis is very much inhibited, whereas a considerable enhancement in the rate of its synthesis takes place. On the basis of these findings the accumulation of glycogen, which has been observed to occur in the liver of the irradiated animal, could be easily explained.

The activity changes of key enzymes involved in glycolysis and gluconeogenesis which were found to occur following x irradiation of the animal,[1-4, 6] could shift the equilibrium conditions of reactions to favor glycogenesis via the UDP-glucose-glycogen pathway. Although it has been found that the activity of phosphofructokinase is considerably enhanced by x irradiation,[3] it does not seem likely that this could cause any appreciable stimulation of glycolysis from liver glycogen because of the decreased availability of glucose-1-P.

At present it is not possible to interpret the activity changes induced by radiation on the enzymes under investigation. Aggregation or disaggregation of the enzyme molecule and the role which cofactors may play should not be excluded.[8]

Decreased levels of nicotinamide dinucleotide, which plays an important role in glycolysis, have been observed in x irradiated cell cultures.[14] Although glucocorticoids do not seem to be involved in the increased deposition of glycogen in x irradiated rats,[17] the role which hormones may play should not be ruled out. Epinephrine, for instance, has been found to increase the production of adenosine-3', 5'-phosphate (cyclic AMP) and the latter plays an important role in the activity of enzymes involved in the breakdown and synthesis of glycogen.[7,23]

## REFERENCES


1. Berndt, J. The content of α-glycerophosphate in mouse liver after whole-body X-irradiation. Int. J. Radiation Biol. 13:187-188, 1967.

2. Berndt, J. and Gaumert, R. Zur Störung des Kohlenhydratstoffwechsels nach Bestrahlung: Einfluss einer Ganzkörperbestrahlung auf den Gehalt an Intermediärprodukten der Glycolyse in der Mäuseleber. Int. J. Radiation Biol. 11:593-604, 1966.

3. Berndt, J. and Gaumert, R. Die Aktivität der Phosphofruktokinase und der Fruktose-1,6-diphosphatase im Lebergewebe der Maus nach Ganzkörperbestrahlung. Int. J. Radiation Biol. 12:453-458, 1967.

4. Berndt, J. and Ulbrich, O. Die Aktivität der Phosphoenolpyruvat-Karboxykinase und der Pyruvatkinase in der Mäuseleber nach einer Ganzkörperbestrahlung. Strahlentherapie 133:288-295, 1967.

5. Cori, G. T. and Cori, C. F. The kinetics of the enzymatic synthesis of glycogen from glucose-1-phosphate. J. Biol. Chem. 135:733-756, 1940.

6. Deshpande, L. D. and Nadkarni, G. B. Enzymes of glucose formation and turnover in X-irradiated rats. Int. J. Radiation Biol. 14:39-47, 1968.

7. Exton, J. H. and Park, C. R. Stimulation of gluconeogenesis from lactate by epinephrine, glucagon, and cyclic 3',5'-adenylate in the perfused rat liver. Pharmacol. Rev. 18:181-188, 1966.

8. Fischer, E. H. and Krebs, E. G. Relationship of structure to function of muscle phosphorylase. Fed. Proc. 25:1511-1520, 1966.

9. Fiske, C. H. and SubbaRow, Y. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375-400, 1925.

10. Hansen, L. The increase in liver glycogen in non-fasted rats after irradiation. A comparison with pair-fed animals. Int. J. Radiation Biol. 12:367-372, 1967.

11. Kay, R. E. and Entenman, C. Hyperglycemia and increased liver glycogen in rats after x-irradiation. Proc. Soc. Exptl. Biol. Med. 91:143-146, 1956.

12. Larner, J. Branching enzyme from liver. In: Methods in Enzymology, Vol. I, pp. 222-225, Colowick, S. P. and Kaplan, N. O., editors. New York, N. Y., Academic Press, 1962.

13. Leloir, L. F. and Cardini, C. E. Biosynthesis of glycogen from uridine diphosphate glucose. J. Am. Chem. Soc. 79:6340-6341, 1957.

14. Maass, H. and Schubert, G. Early biochemical reactions after X-irradiation. Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Vol. 22, pp. 449-454. Geneva, United Nations, 1958.

15. McKee, R. W. and Brin, M. Effects of x-irradiation on glycogenolysis, glycogenesis and gluconeogenesis in the rat. Arch. Biochem. Biophys. 61:390-396, 1956.

16. Montgomery, R. Determination of glycogen. Arch. Biochem. Biophys. 67:378-386, 1957.

17. Nadkarni, G. B. and Deshpande, L. D. Gluconeogenesis in vivo from glycine in X-irradiated rats. Int. J. Radiation Biol. 14:29-38, 1968.

18. Nelson, N. A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153:375-380, 1944.

19. Ross, M. H. and Ely, J. O. Radiation effects on liver glycogen in the rat. J. Cellular Comp. Physiol. 37:163-173, 1951.

20. Streffer, C. Untersuchungen über den Energiestoffwechsel im Lebergewebe der Maus nach Ganzkörperbestrahlung. Int. J. Radiation Biol. 11:179-191, 1966.

21. Strominger, J. L. Mononucleotide acid anhydrides and related compounds as intermediates in metabolic reactions. Physiol. Rev. 40:55-111, 1960.

22. Sutherland, E. W. Polysaccharide phosphorylase, liver. In: Methods in Enzymology, Vol. I, pp. 215-222, Colowick, S. P. and Kaplan, N. O., editors. New York, N. Y., Academic Press, 1962.

23. Sutherland, E. W. and Rall, T. W. The relation of adenosine-3',5'-phosphate and phosphorylase to the actions of catecholamines and other hormones. Pharmacol. Rev. 12:265-299, 1960.

24. Takeuchi, T., Higashi, K. and Watanuki, S. Distribution of amylophosphorylase in various tissues of human and mammalian organs. J. Histochem. Cytochem. 3:485-491, 1955.

25. West, E. S., Todd, W. R., Mason, H. S. and Van Bruggen, J. T. Textbook of Biochemistry, 4th ed., pp. 1043-1044. New York, N. Y., Macmillan, 1966.

DISTRIBUTION LIST

AIR FORCE

The Surgeon General, U. S. Department of the Air Force, Washington, D. C. 20333 (1)
Executive Officer, Director of Professional Services, Office of the Surgeon General, Hq. USAF (AFMSPA) T-8, Washington, D. C. 20333 (1)
Headquarters, U. S. Air Force (AFMSPAB), Washington, D. C. 20333 (1)
USAFSAM (SMBR), ATTN: Chief, Radiobiology Branch, Brooks AFB, Texas 78235 (1)
Air Force Weapons Laboratory, ATTN: WLIL (1), ATTN: WLRB-2 (1), Kirtland AFB, New Mexico 87117 (2)
Chief, Nuclear Medicine Department, P. O. Box 5088, USAF Hospital, Wright-Patterson AFB, Ohio 45433 (1)
Office of the Command Surgeon (ADCSG), Hq. ADC, USAF, Ent AFB, Colorado 80912 (1)
Commander, 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico 88330 (2)

ARMY

The Surgeon General, U. S. Department of the Army, Washington, D. C. 20315 (1)
Surgeon General, ATTN: MEDDH-N, U. S. Department of the Army, Washington, D. C. 20315 (1)
USACDC CSSG, Doctrine Division, Fort Lee, Virginia 23801 (1)
CG, USCONARC, ATTN: ATUTR-TNG (NBC), Fort Monroe, Virginia 23351 (1)
Commanding Officer, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky 40121 (1)
Commanding Officer, USA Nuclear Medical Research Detachment, Europe, APO New York, N. Y. 09180 (2)
Army Research Office, ATTN: Chief, Scientific Analysis Branch, Life Sciences Division, 3045 Columbia Pike, Arlington, Virginia 22204 (1)
Division of Nuclear Medicine, Walter Reed Army Institute of Research, Walter Reed Army Medical Center Washington, D. C. 20012 (5)
Commanding Officer, U. S. Army Environmental Hygiene Agency, ATTN: USAEHA-RP, Edgewood Arsenal, Maryland 21010 (1)
Commandant, U. S. Army Medical Field Service School, ATTN: MEDEW-ZNW, Fort Sam Houston, Texas 78234 (1)

NAVY

Chief, Bureau of Medicine and Surgery, U. S. Navy Department, Washington, D. C. 20390 (1)
Chief, Bureau of Medicine and Surgery, ATTN: Code 71, U. S. Navy Department, Washington, D. C. 20390 (1)
Director, Biological Sciences Division, Office of Naval Research, Washington, D. C. 20360 (1)
Commanding Officer, Naval Aerospace Medical Institute, NAMC, ATTN: Research Director, Pensacola, Florida 32512 (3)
Head, Animal Behavioral Sciences Branch, Naval Aerospace Medical Institute, Naval Aerospace Medical Center, ATTN: Dr. John S. Thach, Jr., Pensacola, Florida 32512 (1)
Commanding Officer, U. S. Naval Hospital, ATTN: Director, REEL, NNMC, Bethesda, Maryland 20014 (1)
Commanding Officer, Nuclear Weapons Training Center, Atlantic, Nuclear Warfare Department, Norfolk, Virginia 23511 (1)
Commanding Officer, Naval Submarine Medical Center, Naval Submarine Base, NL, ATTN: Medical Library, Groton, Connecticut 06340 (1)
Commanding Officer, Naval Submarine Medical Center, Naval Submarine Base, NL, ATTN: Code 53, Nuclear Medicine Training Division, Groton, Connecticut 06340 (1)

D. O. D.

Director, Defense Atomic Support Agency, Washington, D. C. 20305 (1)
Director, Defense Atomic Support Agency, ATTN: DDST, Washington, D. C. 20305 (1)
Director, Defense Atomic Support Agency, ATTN: Chief, Medical Directorate, Washington, D. C. 20305 (4)
Director, Defense Atomic Support Agency, ATTN: Technical Library (APTL), Washington, D. C. 20305 (2)
Commander, Field Command, Defense Atomic Support Agency, ATTN: FC Technical Library, Sandia Base, Albuquerque, New Mexico 87115 (1)
Director, Armed Forces Institute of Pathology, Washington, D. C. 20305 (1)
Administrator, Defense Documentation Center, Cameron Station, Bldg. 5, Alexandria, Virginia 22314 (20)

OTHER GOVERNMENT

U. S. Atomic Energy Commission, Headquarters Library, Reports Section, Mail Station G-17, Washington, D. C. 20545 (1)
U. S. Atomic Energy Commission, Division of Biology and Medicine, Washington, D. C. 20545 (1)
U. S. Atomic Energy Commission, Bethesda Technical Library, 7920 Norfolk Avenue, Bethesda, Maryland 20014 (1)

OTHER GOVERNMENT (continued)

National Aeronautics and Space Administration, ATTN: Lt. Col. Charles M. Barnes, USAF, DB-3, MSC, Houston, Texas 77058 (1)
National Aeronautics and Space Administration, Manned Spacecraft Center, ATTN: Dr. B. D. Newsom, Mail Code DA, Houston, Texas 77058 (1)
National Bureau of Standards, ATTN: Chief, Radiation Physics Division, Washington, D. C. 20234 (1)
U. S. Public Health Service, Bureau of Radiological Health, Division of Biological Effects, 12720 Twinbrook Parkway, Rockville, Maryland 20852 (1)
U. S. Public Health Service, Bureau of Radiological Health, Library, 12720 Twinbrook Parkway, Rockville, Maryland 20852 (1)
U. S. Public Health Service, Northeastern Radiological Health Laboratory, 109 Holton Street, Winchester, Massachusetts 01890 (1)
U. S. Public Health Service, Southeastern Radiological Health Laboratory, P. O. Box 61, Montgomery, Alabama 36101 (1)
U. S. Public Health Service, Southwestern Radiological Health Laboratory, P. O. Box 15027, Las Vegas, Nevada 89114 (1)

OTHER

Argonne National Laboratory, Library Services Department, Report Section Bldg. 203, RM-CE-125, 9700 South Cass Avenue, Argonne, Illinois 60440 (1)
Dr. Donald G. Baker, Radiobiology Department, Zellerbach Saroni Tumor Institute, 1600 Divisadero Street, San Francisco, California 94115 (1)
Dr. J. T. Brennan, Radiology Department, University of Pennsylvania, 3400 Spruce Street, Philadelphia, Pennsylvania 19104 (1)
Brookhaven National Laboratory, Information Division, ATTN: Research Library, Upton, Long Island, New York 11973 (2)
Dr. J. S. Burkle, Director of Nuclear Medicine, York Hospital, York, Pennsylvania 17403 (1)
Director, Radiobiology Laboratory, University of California, Davis, California 95616 (1)
University of California, Lawrence Radiation Laboratory, Library, Bldg. 50, Room 134, Berkeley, California 94720 (1)
University of California, Lawrence Radiation Laboratory, Technical Information Division Library L-3, P. O. Box 808, Livermore, California 94551 (2)
University of California, Laboratory of Nuclear Medicine and Radiation Biology, Library, 900 Veteran Avenue, Los Angeles, California 90024 (1)
Cdr. William H. Chapman, USN (Ret.), Bio-Medical Division L-523, Lawrence Radiation Laboratory, University of California, P. O. Box 808, Livermore, California 94551 (1)
Director, Collaborative Radiological Health Laboratory, Colorado State University, Fort Collins, Colorado 80521 (1)
Dr. L. W. Davis, Radiology Department, University of Pennsylvania, 3400 Spruce Street, Philadelphia, Pennsylvania 19104 (1)
Professor Merril Eisenbud, New York University, Tuxedo, New York 10987 (1)
Dr. T. C. Evans, Radiation Research Laboratory, College of Medicine, University of Iowa, Iowa City, Iowa 52240 (1)
Dr. Arnold Feldman, Institute of Radiology, School of Medicine, Washington University, 510 South Kingshighway, St. Louis, Missouri 63110 (1)
Mr. Orin Gelderloos, Division of Literature, University of Michigan, Dearborn Campus, Dearborn, Michigan 48124 (1)
General Dynamics/Fort Worth, ATTN: Librarian, P. O. Box 748, Fort Worth, Texas 76101 (1)
Gulf General Atomic Incorporated, ATTN: Library, P. O. Box 608, San Diego, California 92112 (1)
IIT Research Institute, ATTN: Document Library, 10 West 35th Street, Chicago, Illinois 60616 (1)
Dr. R. F. Kallman, Department of Radiology, Stanford University, Palo Alto, California 94305 (1)
Dr. L. S. Kelly, Donner Laboratory, University of California at Berkeley, Berkeley, California 94720 (1)
Los Alamos Scientific Laboratory, ATTN: Report Librarian, P. O. Box 1663, Los Alamos, New Mexico 87544 (1)
Director, Nuclear Science Center, Louisiana State University, Baton Rouge, Louisiana 70803 (2)
Lovelace Foundation for Medical Education and Research, Document Library, 5200 Gibson Blvd., S. E., Albuquerque, New Mexico 87108 (1)
Dr. Ross A. McFarland, Guggenheim Professor of Aerospace Health and Safety, Harvard School of Public Health, 665 Huntington Avenue, Boston, Massachusetts 02115 (1)
Dr. J. I. Marcum, Rand Corporation, 1700 Main Street, Santa Monica, California 90401 (1)
Massachusetts Institute of Technology, M.I.T. Librarics, Technical Reports, Room 14 E-210, Cambridge, Massachusetts 02139 (1)

OTHER (continued)

Dr. Charles W. Mays, Physics Group Leader, Radiobiology Division, University of Utah, Salt Lake City, Utah 84112 (1)
Ohio State University, Nuclear Reactor Laboratory, 1298 Kinnear Road, Columbus, Ohio 43212 (1)
Dr. Harvey M. Patt, Laboratory of Radiobiology, University of California, San Francisco Medical Center, San Francisco, California 94122 (1)
Purdue University, Nuclear Engineering Library, Lafayette, Indiana 47907 (1)
Dr. S. M. Reichard, Director, Division of Radiobiology, Medical College of Georgia, Augusta, Georgia 30902 (1)
University of Rochester, Atomic Energy Project Library, P. O. Box 287, Station 3, Rochester, New York 14620 (1)
Dr. H. H. Rossi, 630 West 168th Street, New York, N. Y. 10032 (1)
Dr. Eugene L. Saenger, Director, Radioisotope Laboratory, Cincinnati General Hospital, Cincinnati, Ohio 45229 (1)
Sandia Corporation Library, P. O. Box 5800, Albuquerque, New Mexico 87115 (1)
Scientific Committee on the Effects of Atomic Radiation, ATTN: Library, United Nations Room 3267, United Nations Plaza, New York, N. Y. 10017 (1)
Scope Publications, Franklin Station, P. O. Box 7407, Washington, D. C. 20004 (1)
Dr. Arthur R. Tamplin, Biophysicist, Information Integration Group, University of California, Lawrence Radiation Laboratory, L-612, Livermore, California 94550 (1)
Texas A. and M. University, Radiation Biology Laboratory, Texas Engineering Experiment Station, College Station, Texas 77840 (2)
Texas Nuclear Corporation, ATTN: Director of Research, Box 9267 Allandale Station, Austin, Texas 78756 (1)
Western Reserve University, Department of Radiology, Division of Radiation Biology, Cleveland, Ohio 44106 (1)
Mr. Lionel Zamore, 601 Brightwater Court, Brooklyn, New York 11235 (1)

FOREIGN

International Atomic Energy Agency, Kärntnerring 11, Vienna I, 1010, Austria (1)
European Atomic Energy Community, C. E. E. A., Library, 51 rue Belliard, Brussels 4, Belgium (1)
Dr. L. G. Lajtha, Paterson Laboratories, Christie Hospital and Holt Radium Institute, Manchester, England (1)
Dr. L. F. Lamerton, Biophysics Department, Institute of Cancer Research, Surrey Branch, Belmont, Sutton, Surrey, England (1)
National Lending Library for Science and Technology, Boston Spa, Yorkshire, England (1)
Directorate of Medical and Health Services, FAF (Federal Armed Forces), Bonn, Ermekeilstrasse 27, West Germany (1)
Abteilung für Strahlenbiologie im Institut für Biophysik der Universität Bonn, 53 Bonn-Venusberg, Annaberger Weg 15, Federal Republic of Germany (2)
Prof. Dr. H. Langendorff, Direktor des Radiologischen Instituts der Universität, 78 Freiburg im Breisgau, Albertstrasse 23, Germany (1)
Priv.-Doz. Dr. O. Messerschmidt, Radiologisches Institut der Universität, 78 Freiburg im Breisgau, Albertstrasse 23, Germany (1)
Dr. Helmut Mitschrich, Akademie des Sanitäts- und Gesundheitswesens der Bundeswehr, Spezialstab ATV, 8 München, Schwere Reiterstrasse 4, Germany (2)
Prof. Dr. F. Wachsmann, Gesellschaft für Strahlenforschung m.b.H., 8042 Neuherberg bei München, Institut für Strahlenschutz, Ingolstadter Landstrasse 1, München, Germany (1)
Col. Joachim Emde, Direktor, Spezialstab ATV, ABC- und Selbstschutzschule, 8972 Sonthofen 2/Allgäu, Berghoferstrasse 17, West Germany (1)
Dr. M. Feldman, Section of Cell Biology, The Weizmann Institute of Science, Rehovoth, Israel (1)
Dr. G. W. Barendsen, Radiobiological Institute TNO, Rijswijk, Netherlands (1)
Puerto Rico Nuclear Center, ATTN: Reading Room, College Station, Mayaguez, Puerto Rico 00708 (2)
Dr. H. Cottier, Pathological Institut der Universität, Bern, Switzerland (1)


☆U.S. GOVERNMENT PRINTING OFFICE: 1970-397-174/51

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

1. ORIGINATING ACTIVITY *(Corporate author)*
Armed Forces Radiobiology Research Institute
Defense Atomic Support Agency
Bethesda, Maryland 20014

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
ACTIVITY OF RAT LIVER ENZYMES RESPONSIBLE FOR GLYCOGEN METABOLISM AFTER WHOLE-BODY IRRADIATION

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
G. N. Catravas and C. G. McHale

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| April 1970 | 23 | 25 |

| 8a. CONTRACT OR GRANT NO. | 9a. ORIGINATOR'S REPORT NUMBER(S) |
|---|---|
| b. PROJECT NO. | AFRRI SR70-3 |
| c. MC 3 90101 | 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* |
| d. | |

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited

| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
|---|---|
| | Defense Atomic Support Agency<br>Washington, D. C. 20305 |

13. ABSTRACT

The activities of liver enzymes involved in the breakdown and synthesis of glycogen have been investigated in rats exposed to 1200 rads midline kerma dose, free-in-air, of x rays or mixed gamma-neutron radiation.

It was found that glycogen phosphorylase and amylo-1,6-glucosidase, both of which are involved in the breakdown of glycogen to "glucose" units, are greatly inhibited by both qualities of radiation. A considerable inhibition in the activity of amylo-(1,4 → 1,6)-transglucosidase (branching enzyme) was also observed. In contrast, it was found that the activity of UDP-glucose-glycogen transglucosylase which is responsible for the in vivo synthesis of 1,4-polysaccharides is greatly enhanced when the animal received x rays or mixed gamma-neutron radiation.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

UNCLASSIFIED
Security Classification